(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
10 April 2003 (10.04.2003)

PCT

(10) International Publication Number
WO 03/029739 A2

(51) International Patent Classification[7]: F25J 3/06

(21) International Application Number: PCT/EP02/10907

(22) International Filing Date: 27 September 2002 (27.09.2002)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
01203692.7 28 September 2001 (28.09.2001) EP

(71) Applicant *(for all designated States except US)*: **SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ B.V.** [NL/NL]; Carel van Bylandtlaan 30, NL-2596 HR The Hague (NL).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **BETTING, Marco** [NL/NL]; Volmerlaan 8, NL-2288 GD Rijswijk (NL). **VAN HOLTEN, Theodoor** [NL/NL]; Kluiverweg 1, NL-2629 HS Delft (NL). **PRAST, Bart** [NL/NL]; Volmerlaan 8, NL-2288 GD Rijswijk (NL).

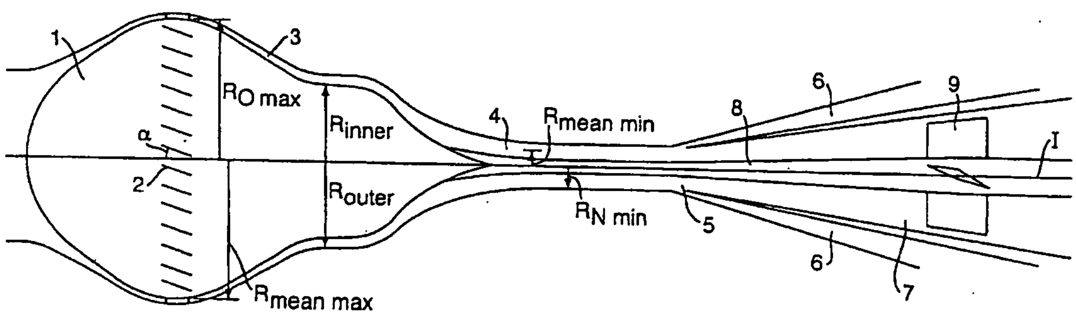
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: CYCLONIC FLUID SEPARATOR WITH VORTEX GENERATOR IN INLET SECTION



(57) Abstract: A cyclonic fluid separator of the type comprising a tubular throat portion (4) in which a fluid mixture is accelerated to a subsonic or supersonic speed and thereby expanded and cooled down so that condensable components condense and/or solidify and then swirl into a diverging fluid outlet section (5) that comprises an aliter secondary outlet (6) for condensables enriched fluid components and an inner primary outlet (7) For condensables depleted fluid components comprises swirl imparting vanes (2) that protrude tram a central body (1) that extends through at least part of an inlet section of the separator, wherein the central body (1) has, at a location upstream of the throat portion (4), a larger aliter width (2Ro max) than the smallest inner width (2R¿n min?) of the throat portion (4).

WO 03/029739 A2

CYCLONIC FLUID SEPARATOR WITH VORTEX GENERATOR IN INLET SECTION

BACKGROUND OF THE INVENTION

The invention relates to a cyclonic fluid separator with a vortex generator located in an inlet section of the generator.

Such cyclonic separators are known from Japanese patent No. 2017921, Russian patent No. 1768242, UK patent application No. 2035151 and PCT patent application WO 00/23757.

The known cyclonic fluid separators comprise a tubular throat portion in which the fluid stream is accelerated to a possibly supersonic speed and rapidly cooled down as a result of adiabatic expansion. The rapid cooling will cause condensation and/or solidification of condensables in the fluid stream into small droplets or particles. If the fluid stream is a natural gas stream emerging from a natural gas production well then the condensables may comprise water, hydrocarbon condensates, waxes and gas hydrates. These separators furthermore comprise an assembly of swirl imparting vanes in an inlet portion upstream of the throat portion, which vane or vanes are tilted or form a helix relative to a central axis of the throat portion to create a swirling motion of the fluid stream within the separator. The centrifugal forces exerted by the swirling motion on the fluid mixture will induce the relatively high density condensed and/or solidified condensables to swirl to the outer periphery of the interior of the throat portion and of a diverging outlet section whereas

relatively low density gaseous components are concentrated near the central axis of the separator. The gaseous components are subsequently discharged from the separator through a primary central outlet.conduit, whereas the condensates enriched fluid stream is discharged from the separator through a secondary outlet which is located at the outer circumference of the diverging outlet section.

A disadvantage of the known vortex generators in the inlet section of the separator is that the amount of rotation imposed on the fluid stream is limited, unless the blades of the vortex generator are oriented at a large angle relative to the central axis of the separator, in which case blades create a high flow restriction in the fluid stream.

An object of the present invention is to arrange in an inlet section cyclonic separator a vortex generator which is able to create a high speed of rotation of the fluid mixture in the throat portion and diverging outlet section of the separator without creating a high flow restriction in the fluid stream.

SUMMARY OF THE INVENTION

The cyclonic fluid separator according to the invention thereto comprises:

- a tubular throat portion which is arranged between a converging fluid inlet section and a diverging fluid outlet section that comprises an outer secondary outlet for condensables enriched fluid components and an inner primary outlet for condensables depleted fluid components; and
- a number of swirl imparting vanes for creating a swirling motion of the fluid within at least part of the separator, which vanes protrude from a central body that

extends through at least part of the inlet section of the separator, wherein the central body has, at a location upstream of the throat portion, a larger outer width than the smallest inner width of the throat portion.

The arrangement of the swirl imparting vanes on a large diameter central body around which the fluid stream is induced to flow and subsequently guided into the relatively small diameter throat portion will enhance the speed of rotation of the fluid stream as a result of the phenomena of preservation of moment of momentum.

The shape of the blade plane can be either flat of curved. It is preferred that the tubular throat portion and the outer surface of the central body are substantially co-axial to a central axis of the separator and the swirl imparting vanes protrude from the outer surface of the central body at or near an area where the central body has a larger outer width than other parts of the central body.

It is also preferred that the central body has a substantially circular, onion-like, shape and comprises upstream of the swirl imparting vanes a dome-shaped nose section of which the diameter gradually increases such that the degree of diameter increase gradually decreases in downstream direction, and the central body further comprises downstream of the swirl imparting vanes a tail section of which the diameter gradually decreases in downstream direction along at least part of the length of the tail section.

Preferably the degree of diameter decrease of the tail section of the central body varies in downstream direction such that the tail section has an intermediate section of which the degree of diameter decrease is smaller than the diameter decrease of adjacent parts of

the tail section that are located upstream and downstream of the intermediate section. In such case the shape of the central body may be described as pear-shaped.

Suitably, the separator comprises a housing in which the central body is arranged such that an annulus is present between the inner surface of the housing and the outer surface of the central body. The width of the annulus may be designed such that cross-axial area of the annulus gradually decreases downstream of the swirl imparting vanes such that in use the fluid velocity in the annulus gradually increases and reaches a supersonic speed at a location downstream of the swirl imparting vanes. In such case the width of the annulus may vary such that at the prevailing pressure difference between the inlet section and the outlet section during normal operation of the separator the fluid flowing through the annulus reaches a supersonic velocity at or near the intermediate section of the tail section of the central body.

Suitably, the tail section may comprise an elongated substantially cylindrical downstream end, which extends substantially co-axial to the central axis through the throat portion and at least part of the diverging fluid outlet section of the separator. Said elongated downstream end may serve as a vortex finder which stabilises and centralises the vortex throughout a major part of the interior of the cyclonic separator. Optionally, a number of flow straightening vanes are mounted on the substantially cylindrical downstream end of the tail section of the central body at a location within the diverging outlet section of the separator, as to transfer tangential momentum in to static pressure increase.

DESCRIPTION OF A PREFERRED EMBODIMENT

The invention will be described in more detail, by way of example, with reference to the accompanying Figure 1, which depicts a longitudinal sectional view of a cyclonic separator according to the invention.

Referring now to Figure 1, there is shown a cyclonic inertia separator which comprises a swirl inlet device comprising a pear-shaped central body 1 on which a series of swirl imparting vanes 2 are mounted and which is arranged co-axial to a central axis I of the separator and inside the separator housing such that an annular flow path 3 is created between the central body 1 and separator housing. The separator further comprises a tubular throat portion 4 from which in use the swirling fluid stream is discharged into a diverging fluid separation chamber 5 which is equipped with a central primary outlet conduit 7 for gaseous components and with an outer secondary outlet conduit 6 for condensables enriched fluid components. The central body 1 has a substantially cylindrical elongate tail section 8 on which an assembly of flow straightening blades 9 is mounted. In accordance with the invention the central body 1 has a largest outer width or diameter 2 R_o max which is larger than the smallest inner width or diameter 2 R_n min of the tubular throat portion 4.

The functions of the various components of the cyclonic fluid separator according to the invention is as follows.

The swirl imparting vanes 2 which are oriented at an angle (α) relative to the central axis I create a circulation (Γ) in the fluid stream. It is preferred that α is between 20° and 30°. The fluid stream is

subsequently induced to flow into the annular flow area 3. The cross-sectional surface of this area is defined as: $A_{annulus} = \pi.(R_{outer}^2 - R_{inner}^2)$. The latter two being the outer radius and inner radius of the annulus at a selected location. The mean radius of the annulus at that location is defined as:

$R_{mean} = \sqrt{[\frac{1}{2}(R_{outer}^2 + R_{inner}^2)]}$

At the maximum value of the mean annulus radius $R_{mean,max}$ the fluid stream is flowing between the assembly of swirl imparting vanes 2 at a velocity (U), which vanes deflect the flow direction of the fluid stream proportional to the deflection angle (α) and so obtaining a tangential velocity component which equals $U_\varphi = U.\sin(\alpha)$ and an axial velocity component $U_x = U.\cos(\alpha)$.

In the annular space 3 downstream of the swirl imparting vanes 2 the swirling fluid stream is expanded to high velocities, wherein the mean annulus radius is gradually decreasing from $R_{mean,max}$ to $R_{mean,min}$.

It is believed that during this annular expansion two processes occur:

(1) The heat or enthalpy in the flow (h) decreases with the amount $\Delta h = -1/2\ U^2$, thereby condensing those flow constituents which first reaching phase equilibrium. This results in a swirling mist flow containing small liquid or solid particles.

(2) The tangential velocity component increases inversely with the mean annulus radius U_φ substantially in accordance with the equation $U_{\varphi,final} = U_{\varphi,initial} \cdot (R_{mean,max}/R_{mean,min})$. This results in a strong increase of the centrifugal acceleration of the

fluid particles (a_c), which will finally be in the order of:

$$a_c = (U_{\varphi,final}^2/R_{mean,min}).$$

In the tubular throat portion 4 the fluid stream may be induced to further expand to higher velocity or be kept at a substantially constant speed. In the first case condensation is ongoing and particles will gain mass. In the latter case condensation is about to stop after a defined relaxation time. In both cases the centrifugal action causes the particles to drift to the outer circumference of the flow area adjacent to the inner wall of the separator housing, which is called the separation area. The time period for the particles to drift to this outer circumference of the flow area determines the length of the tubular throat portion 4.

Downstream of the tubular throat portion 4 the condensables enriched 'wet' fluid components tend to concentrate adjacent to the inner surface of the diverging fluid separation chamber 5 and the 'dry' gaseous fluid components are concentrated at or near the central axis I, whereupon the wet condensables enriched 'wet' fluid components discharged into an outer secondary fluid outlet 6 via a series of slots, (micro)porous portions whereas the 'dry' gaseous components are discharged into the central primary fluid outlet conduit 7.

In the diverging primary fluid outlet conduit 7 the fluid stream is further decelerated so that the remaining kinetic energy is transformed into potential energy. The diverging primary outlet conduit is equipped with an assembly of flow straightening vanes 9 to recover the circulation energy.

CLAIMS

1. A cyclonic fluid separator comprising:

- a tubular throat portion which is arranged between a converging fluid inlet section and a diverging fluid outlet section that comprises an outer secondary outlet for condensables enriched fluid components and an inner primary outlet for condensables depleted fluid components; and

- a number of swirl imparting vanes for creating a swirling motion of the fluid within at least part of the separator, which vanes protrude from a central body that extends through at least part of the inlet section of the separator , wherein the central body has, at a location upstream of the throat portion, a larger outer width than the smallest inner width of the throat portion.

2. The separator of claim 1, wherein the tubular throat portion and the outer surface of the central body are substantially co-axial to a central axis of the separator and the swirl imparting vanes protrude from the outer surface of the central body at or near an area where the central body has a larger outer width than other parts of the central body.

3. The separator of claim 2, wherein the central body has a substantially circular shape in a cross-axial direction and comprises upstream of the swirl imparting vanes a nose section of which the diameter gradually increases such that the degree of diameter increase gradually decreases in downstream direction, and the central body further comprises downstream of the swirl imparting vanes a tail section of which the diameter

gradually decreases in downstream direction along at least part of the length of the tail section.

4. The separator of claim 3, wherein the degree of diameter decrease of the tail section of the central body varies in downstream direction such that the tail section has an intermediate section of which the degree of diameter decrease is smaller than the diameter decrease of adjacent parts of the tail section that are located upstream and downstream of the intermediate section.

5. The separator of any one of claims 1-4, wherein the separator comprises a housing in which the central body is arranged such that an annulus is present between the inner surface of the housing and the outer surface of the central body.

6. The separator of claim 5, wherein the width of the annulus is designed such that the cross-sectional area of the annulus gradually decreases downstream of the swirl imparting vanes such that in use the fluid velocity in the annulus gradually increases and reaches a supersonic speed at a location downstream of the swirl imparting vanes.

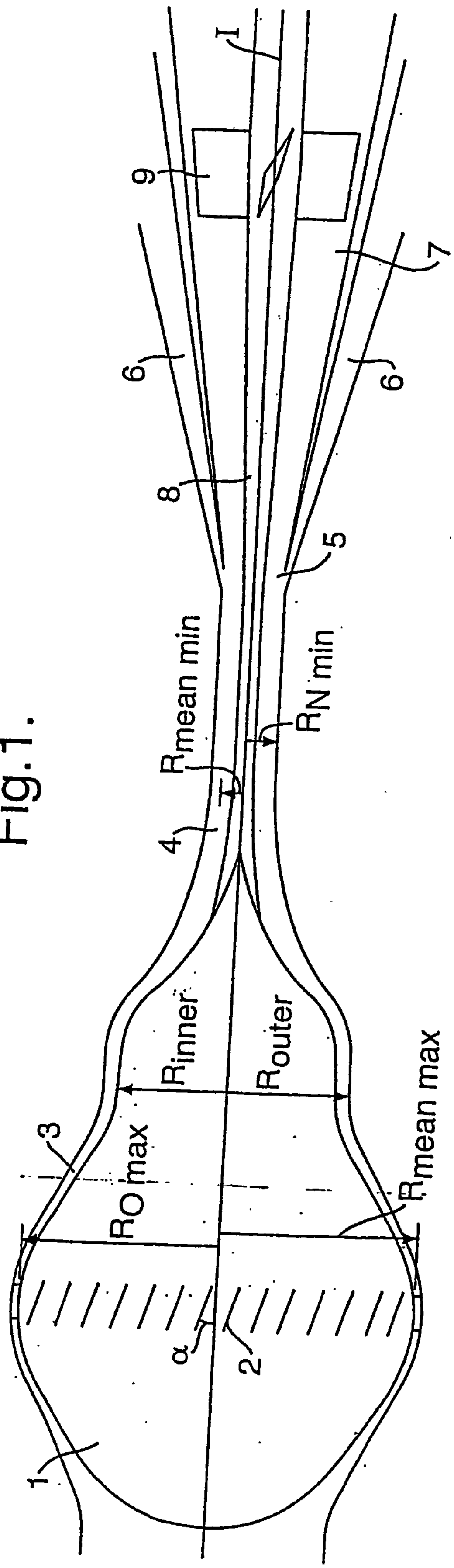
7. The separator of claims 4 and 6, wherein the width of the annulus varies such that at the prevailing pressure difference between the inlet section and the outlet section during normal operation of the separator the fluid flowing through the annulus reaches a supersonic velocity at or near the intermediate section of the tail section of the central body.

8. The separator of claim 3, wherein the tail section comprises an elongated substantially cylindrical downstream end which extends substantially co-axial to the central axis through the throat portion and at least

part of the diverging fluid outlet section of the separator.

9. The separator of claim 8, wherein a number of flow straightening vanes are mounted on the substantially cylindrical downstream end of the tail section of the central body at a location within the diverging outlet section of the separator downstream of the secondary outlet for liquid enriched fluid components.

Fig.1.


I
9
7
6
6
8
5
$R_{mean\ min}$
$R_{N\ min}$
4
R_{inner}
R_{outer}
3
$R_{O\ max}$
$R_{mean\ max}$
α
2
1

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
10 April 2003 (10.04.2003)

PCT

(10) International Publication Number
WO 03/029739 A3

(51) International Patent Classification[7]: F25J 3/06, 3/08, B01D 45/12

(21) International Application Number: PCT/EP02/10907

(22) International Filing Date: 27 September 2002 (27.09.2002)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
01203692.7 28 September 2001 (28.09.2001) EP

(71) Applicant *(for all designated States except US)*: **SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ B.V.** [NL/NL]; Carel van Bylandtlaan 30, NL-2596 HR The Hague (NL).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **BETTING, Marco** [NL/NL]; Volmerlaan 8, NL-2288 GD Rijswijk (NL). **VAN HOLTEN, Theodoor** [NL/NL]; Kluiverweg 1, NL-2629 HS Delft (NL). **PRAST, Bart** [NL/NL]; Volmerlaan 8, NL-2288 GD Rijswijk (NL).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZM, ZW.

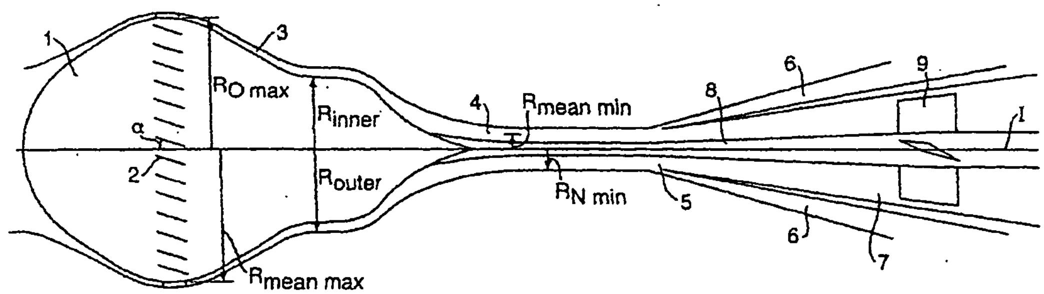
(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

(88) Date of publication of the international search report: 28 August 2003

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: CYCLONIC FLUID SEPARATOR WITH VORTEX GENERATOR IN INLET SECTION



(57) Abstract: A cyclonic fluid separator of the type comprising a tubular throat portion (4) in which a fluid mixture is accelerated to a subsonic or supersonic speed and thereby expanded and cooled down so that condensable components condense and/or solidify and then swirl into a diverging fluid outlet section (5) that comprises an aliter secondary outlet (6) for condensables enriched fluid components and an inner primary outlet (7) For condensables depleted fluid components comprises swirl imparting vanes (2) that protrude tram a central body (1) that extends through at least part of an inlet section of the separator, wherein the central body (1) has, at a location upstream of the throat portion (4), a larger aliter width (2Ro max) than the smallest inner width (2R¿n min?) of the throat portion (4).

WO 03/029739 A3

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 02/10907

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F25J3/06 F25J3/08 B01D45/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 F25J B01D B04C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
PAJ, EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PATENT ABSTRACTS OF JAPAN vol. 014, no. 146 (C-0704), 20 March 1990 (1990-03-20) & JP 02 017921 A (MITSUBISHI HEAVY IND LTD), 22 January 1990 (1990-01-22) cited in the application abstract	1-9
A	GB 901 290 A (PARSONS C A & CO LTD) 18 July 1962 (1962-07-18) page 2, line 70 - line 81; figure 5 page 3, line 15 - line 23	1-9
A	EP 0 420 503 A (ATOMIC ENERGY AUTHORITY UK) 3 April 1991 (1991-04-03) column 2, line 26 - line 44; figure 2	1-9

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 January 2003	27/01/2003

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Göritz, D

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 02/10907

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 746 340 A (DURRE REYNOLD F ET AL) 24 May 1988 (1988-05-24) column 4, line 14 - line 24; figure 4 -----	1-9

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/EP 02/10907

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
JP 02017921	A	22-01-1990	NONE		
GB 901290	A	18-07-1962	FR	1278323 A	08-12-1961
EP 0420503	A	03-04-1991	AU	631248 B2	19-11-1992
			AU	6305590 A	28-03-1991
			CA	2025709 A1	24-03-1991
			EP	0420503 A2	03-04-1991
			GB	2236060 A ,B	27-03-1991
			JP	3118803 A	21-05-1991
			NO	904096 A	25-03-1991
			US	5064449 A	12-11-1991
US 4746340	A	24-05-1988	NONE		